

FINAL REPORT  
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## **FINAL TECHNICAL REPORT**

**NASA COOPERATIVE AGREEMENT NCC-789**  
**"Investigations in Martian Sedimentology"**

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### *PI's Relevant, Recent Publications*

1. Moore, J.M., G.D. Clow, W.L. Davis, V.C. Gulick, D.R. Janke, C.P. McKay, C.R. Stoker, and A.P. Zent (1995) The Circum-Chryse region as a possible example of a hydrologic cycle on Mars: Geologic observations and theoretical evaluation, *J. Geophys. Res.*, *100*, 5433-5447.
2. Moore, J.M., M.T. Mellon and A.P. Zent (1996) Mass wasting and ground collapse in terrains of volatile-rich deposits as a solar system process: the pre-Galileo view, *Icarus*, *122*, 63-78.
3. McEwen, A.S., J.M. Moore, E.M. Shoemaker (1997) The Phanerozoic impact flux: Evidence from the Farside of the Moon, *J. Geophys. Res.*, *102*, 9231-9242.
4. Schenk, P.M. and J.M. Moore (1997) Geologic landforms and processes on icy satellites, in *Solar System Ices*, B. Schmitt, C. de Bergh, F. Foucau, eds., pp 551-578, Kluwer Academic Publishers, Dordrecht, The Netherlands..
5. Moore, J.M. and M.A. Bullock (1999) Experimental studies of Mars-analog brines, *J. Geophys. Res.*, *104*, 21925-21934.
6. Moore, J.M., E. Asphaug, R.J. Sullivan, J.E. Klemaszewski, K.C. Bender, R. Greeley, P.E. Geissler, A.S. McEwen, E.P. Turtle, C.B. Phillips, B.R. Tufts, J.W. Head III, R.T. Pappalardo, K.B. Jones, C.R. Chapman, M.J.S. Belton, R.L. Kirk, and D. Morrison (1998) Large impact features on Europa: Results from the Galileo nominal mission, *Icarus*, *135*, 127-145..
7. Moore, J.M., E. Asphaug, D. Morrison, J.E. Klemaszewski, R.J. Sullivan, F. Chuang, R. Greeley, K.C. Bender, P.E. Geissler, C.R. Chapman, P. Helfenstein, C.B. Pilcher, R.L. Kirk, B. Giese, and J.R. Spencer (1999) Mass movement and landform degradation on the icy Galilean satellites: Results from the Galileo nominal mission, *Icarus*, *140*, 294-312..

## **NCC2-789 REPORT ON WORK 1993-1998** ***"Investigations in Martian Sedimentology"***

### **TASK I. CHARACTERIZATION OF MARTIAN FLUIDS AND CHEMICAL SEDIMENTS**

#### ***A. Introduction***

Evaporite deposits may represent significant sinks of mobile anions (e.g. Ca, Mg, Fe) and cations (e.g. C, N, S, Cl) for martian boundary layer materials. (Carbon and nitrogen are especially interesting because of their importance to organic chemical processes.) The nature of evaporites formed under martian conditions is poorly understood. Laboratory studies investigating the formation of brines and evaporites would greatly aid in improving our understanding of these materials. To date, only a very limited number of laboratory investigations have been conducted (e.g. Booth and Kieffer, 1978; Gooding, 1989) which have any bearing on a better understanding of various processes related to evaporate and brine formation or characterization on Mars.

#### ***B. Progress***

We received local spending authority to acquire components, materials and supplies for the assembly of the experimental apparatus, secure laboratory space and (separate) apparatus assembly space, and supplies of gases, minerals, and other consumables to be used in the experiment. The experiment commenced in November 1998. Itemized activities were:

1. We established the laboratory set-up to simultaneously run all 108 vessels, grouped in three separate temperature controlled environments.
2. We established the necessary lab fixturing, chemical supplies, etc. to make batches of fresh run material and to analyze fluid and rock components of completed runs.
3. We initiated first (year-long) cycle brine experiment (see Table 1), and analyzed samples and reduced the data.

Table 1. Experimental Matrix for Proposed Brines Experiment

## COMMON RUN TEMPLATE

Batch Number*	Time Step Duration (in days)	Sample Composition
1	1	Water / Rock / Mars Gas <sup>1</sup> or 2
2	1	Water / Rock / Earth Gas (Control)
3	1	Water / Mars Gas (Control)
4	21 (3 wk)	Water / Rock / Mars Gas
5	42 (6 wk)	Water / Rock / Mars Gas
6	84 (12 wk)	Water / Rock / Mars Gas
7	84 (12 wk)	Water / Rock / Earth Gas (Control)
8	84 (12 wk)	Water / Mars Gas (Control)
9	168 (24 wk)	Water / Rock / Mars Gas
10	336 (48 wk)	Water / Rock / Mars Gas
11	336 (48 wk)	Water / Rock / Earth Gas (Control)
12	336 (48 wk)	Water / Mars Gas (Control)

\* Each batch consist of 3 samples

**First Cycle:**

Run 1: "whole martian" (crystalline) mineral mix<sup>3</sup> at 1°C and 1 bar "Mars gas"<sup>1</sup>.

Run 2: "whole martian" (crystalline) mineral mix at 30°C and 1 bar "Mars gas"<sup>1</sup>.

Run 3: "whole martian" (crystalline) mineral mix at 50°C and 1 bar "Mars gas"<sup>1</sup>.

**Second Cycle:**

Run 4: "whole martian" (crystalline) mineral mix at 1°C and 1 bar "paleo-Mars gas"<sup>2</sup>.

Run 5: "whole martian" (crystalline) mineral mix at 30°C and 1 bar "paleo-Mars gas"<sup>2</sup>.

Run 6: "whole martian" (crystalline) mineral mix at 50°C and 1 bar "paleo-Mars gas"<sup>2</sup>.

**Third Cycle:**

Run 7: "whole martian" (vitrified) mineral mix at 30°C and 1 bar "Mars gas"<sup>1</sup>.

Run 8: "mixture A"<sup>4</sup> (crystalline) mineral mix at 30°C and 1 bar "Mars gas"<sup>1</sup>.

Run 9: "mixture B"<sup>5</sup> (crystalline) mineral mix at 30°C and 1 bar "Mars gas"<sup>1</sup>.

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1. Mars Gas: CO<sub>2</sub> 95.50%, N<sub>2</sub> 2.70%, Ar 1.60%, O<sub>2</sub> 0.13%, CO 0.07%

2. paleo-Mars gas: CO<sub>2</sub> 70%, N<sub>2</sub> 12% CO 10%, O<sub>2</sub> 5%, SO<sub>2</sub> 1%, NO<sub>2</sub> 1%, CH<sub>4</sub> 0.9%, NH<sub>3</sub> 0.1%

3. "Whole martian" mineral mix: 57.2% augite, 25.26% forsterite, 13.14% andesine, 3.14% ilmenite, 0.78% pyrite, and 0.48% chloro-apatite

4. Mixture A: 57.2% augite, 25.26% forsterite, 13.14% andesine, 4.40% ilmenite

5. Mixture B: 57.2% augite, 25.26% forsterite, 13.14% andesine, 2.20% ilmenite, 2.20% pyrite

## TASK II. MASS WASTING AND GROUND COLLAPSE IN TERRAINS OF VOLATILE-RICH DEPOSITS

### A. Introduction

The goal of this task is to recognize the extent of sublimation degradation as a significant geologic process on the surface of Mars, as well as on the surfaces of outer-planet satellites. Following the geomorphic description and categorization of manifestations of sublimation degradation on Mars (and elsewhere), modelling will be utilized to evaluate the physical parameters which are thought to control the evolution and eventual equilibrium stabilization of these landforms. Finally tests utilizing forthcoming spacecraft data will be proposed to place new observational constraints on parameters identified in this investigation and to verify hypotheses arising from this study.

### B. Progress:

First, a study was made to identify landforms that may have been produced by volatile loss-driven mass wasting and ground collapse. An examination of spacecraft images of Mars, Io, Europa, Ganymede and Triton revealed a number of candidate landforms. These landforms tend to fall between two end-member cases. Case one is that of scarp retreat. The best examples are seen in martian south polar terrains where craters above scarp brinks are destroyed as the scarp retreats through them, leaving no trace on the surface below the scarp foot. The second end-member is that of scarp-bounded enclosed depressions or pits. The formation of the pits are speculated to be the result of the decay of thick but laterally limited lenses of volatile. Scarp retreat, on the other hand, is thought to be due to the progressive undermining of a cap rock underlain by an areally extensive layer of volatile-rich material. A preliminary code describing the process has been developed. This model was initially tested using the case of H<sub>2</sub>O sublimation on Ganymede. Sublimation of H<sub>2</sub>O can only produce visible landforms on Ganymede under exceptional circumstances. The global heat-flow must be high (30 mW m<sup>-2</sup>), the conductivity must be quite low ( $7 \times 10^{-3} \text{ J m}^{-1} \text{ s}^{-1} \text{ K}^{-1}$ ), and the conditions must be maintained for  $\sim 10^8$  years in order to produce  $\sim 100$  m of relief. More typical conditions do not permit substantial sublimation from the substrate. These preliminary results were reported at the October 1993 meeting of the Division for Planetary Sciences of the American Astronomical Association (Moore, J.M., A.P. Zent, and D.P. Cruikshank, Mass wasting and ground collapse on terrains of volatile-rich deposits on Mars and some outer-planet satellites (abs.), *Bull. Amer. Astron. Soc.*, 25, 1112, 1993). Additional results were presented at the Icy Galilean Satellites Conference held in San Juan Capistrano, CA, in February of 1994 (Moore, J.M. and A.P. Zent, Landform degradation and mass wasting on the icy Galilean satellites (abs.), *Icy Galilean Satellites Conference, Capistrano Conference No. 4*, p.p. 57-58, 1994; and Moore, J.M., M.T. Mellon and A.P. Zent (1995) Mass wasting and ground collapse on terrains of volatile-rich deposits as a solar system-wide geological process: The pre-Galileo view (abs.), in *Solar System Ices: An International Symposium* abstracts volume, p. 84, 27-30 March 1995, Toulouse, France.). We also published a paper in *Icarus* entitled "Mass wasting and ground collapse in terrains of volatile-rich deposits as a solar system process: the pre-Galileo view." At the 1997 Lunar and Planetary Science Conference we reported the results of the analysis of these features in images acquired during the first half of the nominal Galileo Orbiter mission (Moore, J.M. et al. Landform Degradation and Mass Wasting on the Icy Galilean Satellites (abs.) Lunar Planet. Sci. Conf. XXVIII, 971-972, 1997). A paper entitled "Mass Movement and Landform Degradation on the Icy Galilean Satellites: Results of the Galileo Nominal Mission" has been submitted to *Icarus*. This task is completed.

### **TASK III: MARS ROVER TERRESTRIAL FIELD INVESTIGATIONS**

#### ***A. Introduction***

The purpose of this experiment is to perform a simulation of a Mars surface rover mission. This mission simulation will be performed in support of the proposed joint Russian-American Mars mission called "Mars Together". The Marsokhod planetary surface rover will be deployed in a field site in the American Southwest desert. The Marsokhod is a Russian-built planetary surface rover currently residing at NASA Ames Research center. The Marsokhod rover is equipped with American avionics, computers, and science instruments. It will be controlled by mission operations teams located at NASA Ames in Moffett Field California (USA) and at Levochkin Association in Moscow (Russia). Teams located at each organization will operate the rover for part of each day of the mission simulation. The Virtual Environment Vehicle Interface (VEVI) rover control software will be used to operate the rover at each control site. Vevi is based on a distributed control concept which allows different users at connected internet sites to alternately control the rover motion. Science teams stationed in Moscow and at NASA Ames will direct the rover traverse in order to maximize science return during the mission simulation. Communication with the rover was performed via a portable satellite communication antenna stationed in the field near the rover. The total mission simulation occurred over several 7-day periods.

#### ***B. Progress:***

We spent a year reconfiguring and upgrading the rover in preparation for the 1998-99 field season which was scheduled for January 1999. In August of 1998, we took advantage of the opportunity to purchase the rover outright from the Russians. We acquired an integrated chemical analyzer and data recorder for the rover.

### **TASK IV: MARS PATHFINDER OPERATIONS SUPPORT**

#### ***A. Objectives:***

The Pathfinder mission has the potential to provide key information on the geologic, climatic, and biological history of Mars using the combined capabilities of the IMP camera on the lander and the rover. The ability to identify features of interest using IMP and then investigate them closely with the rover provides unique scientific capabilities, but also affords unique challenges to performing the mission. Because the baseline rover mission is relatively short (7 days), time critical decisions must be made on the basis of initial downlinks of IMP camera images to determine how to target the rover to get the best access to this information. Efficient rover operations and rapid scientific decision making will be critical to achieving mission goals.

Our proposed investigation has two main objectives: 1) Analyze the Pathfinder landing site to look for any evidence of biological activity or other clues to the climatic and biological history of Mars. 2) Provide the Pathfinder project with state of the art graphical visualization tools to enhance the efficiency of rover operations during the mission and provide enhanced capabilities for scientific analysis and public presentation of the mission results.

#### ***B. Progress:***

During the lifetime of Mars Pathfinder our research group provided essential 3D model rendering support to the Science Data Analysis Team. Several papers have been submitted to several peer-review journals (Science, J. Geophys. Res) reporting the results of this activity and its contribution to science analysis. This task is completed.

## **TASK 5: MARTIAN SUBSURFACE WATER INSTRUMENT**

### ***A. Objectives:***

The objective of this study is to form a scientific team for the purpose of defining, justifying, and advocating the development of an instrument capable of determining the location of water on Mars in the course of near-term missions. A further objective is to develop an instrument and mission concept capable of conducting the water detection investigations and to lay the groundwork for proposing the concept to Mars Surveyor, Discovery, or other foreseeable mission opportunities.

### ***B. Progress:***

Initial feasibility analysis has been conducted in conjunction with Lockheed-Martin in Denver. The first instrument definition team meeting was held in January 1998. This task is completed.